Air Resources Board

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MAC #2002-02

May 14, 2002

TO: ALL PASSENGER CAR MANUFACTURERS
ALL LIGHT-DUTY TRUCK MANUFACTURERS
ALL MEDIUM-DUTY VEHICLE MANUFACTURERS
ALL OTHER INTERESTED PARTIES

SUBJECT: USE OF BAG MINI-DILUTER SAMPLING SYSTEMS IN LIEU OF CONSTANT VOLUME SAMPLING FOR MASS EMISSIONS TESTING

This letter transmits the attached Manufacturers Advisory Correspondence (MAC) that provides the Air Resources Board's (ARB's) policy allowing a manufacturer the option of using United States Environmental Protection Agency (U.S. EPA)-approved bag mini-diluter (BMD) systems to measure exhaust emissions from passenger cars, light-duty trucks and medium-duty vehicles. The U.S. EPA-approved BMD systems may be used in lieu of constant volume sampling systems (CVS) required in part B of the California Non-Methane Organic Gas (NMOG) Test Procedures.

Should you have any questions or comments, please contact Paul Hughes, Manager of the Low-Emission Vehicle Implementation Section at (626) 575-6977 or by e-mail at phughes@arb.ca.gov.

Sincerely,

Robert H. Cross, Chief
Mobile Source Control Division

Attachment

Optional Use of Bag Mini-Diluter Systems in Lieu of Constant Volume Sampling Systems

APPLICABILITY

All 2002 and subsequent model passenger cars, light-duty trucks and medium-duty complete vehicles up to 14,000 pounds gross vehicle weight rating.

REFERENCES:

1. California Code of Regulations, Title 13, section 1961.
2. "California Exhaust Emission Standards and Test Procedures for 2001 and Subsequent Model Passenger Cars, Light-Duty Trucks, and Medium-Duty Vehicles," as last amended December 27, 2000.
3 "California Non-Methane Organic Gas Test Procedures" as last amended August 5, 1999.
4. Title 40, Code of Federal Regulations, section 86.109-94, "Exhaust gas sampling system; as last amended June 30, 1995.

DISCUSSION

The adoption of the Low-Emission Vehicle Program II (LEV II) emission standards for passenger cars, light-duty trucks and medium-duty vehicles requires sampling systems capable of accurately measuring low levels of exhaust emissions. While conventional CVS sampling systems are theoretically able to perform adequately at low emission levels, there are inherent operational characteristics in the CVS system that can produce less satisfactory results. This is especially true for the ultra-low emission vehicle (ULEV) and super ultra-low emission vehicle (SULEV) standards.

In response to these concerns, the U.S. EPA, ARB and the Environmental Research Consortium (ERC) have developed an alternative sampling system to more accurately measure exhaust emissions, called the bag mini-diluter (BMD) system. The U.S. EPA has issued a Dear Manufacturer letter (CCD-01-23 dated December 6, 2001) that sets forth the criteria for acceptance of a sampling system other than the CVS systems.

POLICY

The California NMOG Test Procedures allow a manufacturer to use an alternative measurement procedure provided it can demonstrate that the alternative method yields equivalent results and if approved in advance by the Executive Officer. The ARB will therefore allow a manufacturer to use a U.S. EPA-approved BMD system as an alternative to CVS sampling as long as the proposed system meets the criteria set forth in the EPA Dear Manufacturer letter CCD-01-23 December 6, 2001. A copy of the Dear Manufacturer letter is attached to this MAC for reference.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
NATIONAL VEHICLE AND FUEL EMISSIONS LABORATORY
2565 PLYMOUTH ROAD
ANN ARBOR, MICHIGAN 48105-2498

OFFICE OF
AIR AND RADIATION

December 6, 2001

CCD-01-23 (LDV/LDT/MDV)

Subject: Use of Bag Mini-Diluter Sampling Systems in Lieu of Constant Volume Sampling for Mass Emissions Testing

The adoption of new low emission standards for Light Duty Vehicles (LDVs), Light Duty Trucks (LDTs), and Medium Duty Vehicles (MDVs) under EPA Tier 2 and California LEV II regulations require sampling systems capable of accurately measuring low levels of exhaust emissions. Conventional CVS sampling systems, while theoretically able to perform adequately at low emission levels, have inherent operational characteristics which, if not specifically addressed, can produce less satisfactory results. These occur at the lower bins (bin 3 and lower) of the Tier 2 standards, and at the Ultra-low Emitting Vehicle (ULEV), and Super Ultra-low Emitting Vehicle (SULEV) standards for passenger car and LDTs of the LEV II standards. In particular, CVS systems at these very low emission levels are affected by water condensation, non-optimal dilution ratios, and ambient background concentrations. Other factors affecting emission measurement accuracy are system-generated hydrocarbons and vehicles which do not operate at stoichiometric air/fuel ratios, or have fuel shutoff strategies.

In response to these concerns, vehicle manufacturers and equipment vendors have developed an alternative sampling system to more accurately measure exhaust emissions, called the bag mini-diluter (BMD) system. 40 CFR 86.109-94(a)(6) allows vehicle manufacturers to use alternative sampling systems provided they are shown to be equivalent or better than current constant volume sampling (CVS) systems, and approved in advance by EPA. By this letter, EPA is approving usage of bag mini-diluter systems based on our Laboratory Operations Division's (LOD) review of the technical submission dated May 1, 2001 sent from the Environmental Research Consortium (ERC), whose membership consists of Ford, DaimlerChrysler, and General Motors, to Gregory A. Green, Director, Compliance and Certification Division. While CVS systems are still permitted, manufacturers should determine any modifications which may be needed to address the above-mentioned effects.

The advantages of BMD systems are described in detail in the ERC May 1 submission, and also briefly described in the attachments to this letter prepared by LOD. The attachments present a description of the BMD system, a comparison of the BMD and CVS sampling methods, and a brief discussion of quality control practices for BMD and CVS systems. Auto manufacturers, equipment vendors, and EPA have been active in developing, reviewing, and proving the BMD concept since 1992.

All non-confidential information, including a theoretical description of the BMD concept, technical specifications, vehicle testing trials, quality control practices, and supporting information is available on the United States Council for Automotive Research (USCAR) website at: www.uscar.org/ERC/BMDreport.htm.
While there is no charge for using this technology, please note that it is patented. A licensing agreement is available at http://www.uscar.org/consortia/con-erc.htm

EPA is not requiring the use of a BMD system at present, but the system has distinct advantages over the current CVS system. The use of BMD systems, or equivalent technology, is strongly encouraged for LDV, LDT, and MDV emission measurement at the lower EPA Tier 2 and California LEV II standards, and also for the current ULEV standards for LDVs and LDTs. EPA believes BMD technology will eliminate previous problems where manufacturers have observed negative mass emissions when measuring low concentrations of exhaust gases. The topic of negative emissions, and mention of BMD systems as a technology to avoid them, was previously discussed in EPA Dear Manufacturer letter CCD-01-01, February 8, 2001. The use of BMD systems requires no changes in reporting mass emissions to the EPA Certification and Fuel Economy Information System (CFEIS).

Requests for EPA approval to use alternative sampling systems should be addressed to your EPA contact in the Certification and Compliance Division (as provided in Manufacturer Guidance Letter CCD-01-18). Approvals will be straightforward if the proposed sampling system is similar in design, operation, and quality control practices to the submission described on the USCAR website. Significant deviations from these designs will require more review time for the technical staff of LOD. A request for usage of an alternative sampling system should, at minimum, include information on the theory of operation, component descriptions, commissioning tests including comparative vehicle emission results, and calibration/quality control requirements.

If you have questions concerning technical aspects of the ERC Bag Mini-Diluter submission, call Don Paulsell (734-214-4255) or Carl Ryan (734-214-4251) of the Laboratory Operations Division. If you have questions concerning the usage of the BMD system for compliance with current and future light duty vehicle and truck emission standards call Martin Reineman (734-214-4430) of the Certification and Compliance Division.

Sincerely,

Gregory A. Green

Gregory A. Green, Director
Certification and Compliance Division
Office of Transportation and Air Quality

Attachments

Attachment

Considerations and Guidance Regarding the Use of Bag Mini-Diluter Technology
Prepared by the EPA Laboratory Operations Division

The following paragraphs briefly summarize the differences between the classic CVS sampling methodology described in the CFR and the alternative emissions sampling methodology that is called the bag mini-diluter (BMD). These two systems are shown schematically at the end of this attachment, where the important design elements of the CVS and BMD systems are highlighted.

The process of quantifying vehicle emissions on a mass basis has been done since 1972 using the CVS method. The BMD offers several advantages over the CVS when measuring very low emission levels, such as bin 3 and lower standards under Federal Tier 2 regulations and ULEV and SULEV standards under California LEV II regulations. Although both CVS and BMD systems should address the following prerequisites to assure good sample integrity when measuring low emission levels, the BMD system was developed to optimize these criteria:

Eliminate water condensation
Minimize and optimize the dilution ratio
Minimize the effects of dilution gas background concentrations
Reduce system generated hydrocarbons

The BMD utilizes "bone" dry heated zero air for the constant 5:1 dilution ratio (DR), which is maintained heated at 180 deg F to assure no condensation occurs. At the same time, this constant dilution of a near stoichiometric combustion process will produce the same CO_2 bag concentration for all test phases, thus providing a useful quality assessment parameter. This 6:1 constant dilution factor (DF = DR+1) provides average bag concentrations that are similar to the CVS method, but eliminates the need to subtract the adjusted background levels, thus improving the overall measurement precision. It has been determined that materials (such as bags, valves, and pumps) used in the sample handling systems can generate hydrocarbons that were not emitted from the vehicle. When vehicle emissions were higher, the difference between sample and ambient levels made this insignificant. However, for a low emitting Tier 2 or LEV II vehicle, the subtraction of two small HC concentration values to determine the net concentration introduces an inherent component of variability on the net concentration. The BMD eliminates this subtraction process.

There are several important measurement components in the BMD system. The real time measurement and integration of the transient flow rate of raw exhaust is critical. This exhaust can vary from pulsating flow at idle to values 70 times higher during accelerations. The direct exhaust flow meter must have the dynamic range and responsiveness to determine all flow rates accurately on a second by second basis. The quantity of the constant ratio diluted exhaust must be collected in a bag on a continuously proportional time delayed basis. This requires that a sample transport delay time has been quantified and integrated into the proportioning device, which has typically been a mass flow controller (MFC). The use of the MFC in the BMD provides the required proportionality, but its flow can also be scaled for different sample phase times to fill each bag to 80% of capacity. The CVS method is inherently simpler, but the dilution ratio varies from 100:1 at idle to perhaps 4:1 at high exhaust flows, which can induce localized condensation at any "cold" spot. The sample proportionality is typically achieved in the CVS by use of a small CFV in front of the main dilute flow CFV, thus assuring flow symmetry over the total CFV flow variations caused by varying inlet temperatures. The fixed diameter small CFV produces variable bag fill percentages for a given bag size and phase duration. The BMD can fill each bag to the same percentage, which minimizes any effect from the residual dead volume in the fill circuit.

Conventional CVS systems are still acceptable, but careful attention must be given to the four items highlighted above, in particular for emission measurements at very low emission levels. Many users have enhanced their CFV systems to address some of the problem areas. Dilution air flow can be measured, integrated, and proportionally sampled to determine the background emission mass directly as is done for the mixture. The net vehicle mass emission is then a direct subtraction with no need for the calculated adjustment factor (1-1/DF). This (1-1/DF) adjustment factor was specified in 1973 as an approximation for the total dilution air volume which is less than the total dilute exhaust volume and was based on the assumptions of stoichiometric combustion of a specific fuel. In modern emission control systems, lean burn and fuel shutoff technologies cause lower CO_2 levels which then overstates the DF, and this results in too much ambient sample being subtracted. For a vehicle that truly emits close to zero emissions, this over compensation can result in a calculated vehicle mass emission that is negative. Based on the definition of emissions in 40 CFR 86.082-2(b) and on the principles of physics, a negative mass is not possible.

Dilution air can also be dried and heated and variable flow CVS systems can be use to optimize dilution and prevent condensation. Condensation not only removes the vapor as part of the diluent which will increase all the other concentrations, but, based on specific gas solubility, can also remove other gases. In some systems, dilution air has been catalytically scrubbed, but this does not alter the analysis and subtraction process, nor eliminate the potential bag HC generation effect. An alternative material to the Tedlar sample bags will be recommended for BMD and enhanced CVS systems from a study being conducted by EPA, CARB, and an industry consortium. HC generation from Tedlar and the affects of heat and humidity in the sample are being studied as well. Condensation at any point in the sample process can alter the integrity of the sample.

The BMD has been approved as a viable alternative to the CVS method for the three companies who have researched, developed, and demonstrated the accuracy, precision, and comparative results of the BMD. It offers some advantages in terms of sample collection and analysis, but requires regular calibration and quality control monitoring to assure the exhaust volume is accurate and the sample is representative. The exhaust mass, dilution factor, sample proportionality, sample integrity and concentration analysis each directly affect the indicated result. Both the CVS and BMD sampling systems should have built in checks and independent verification procedures to assure the accuracy and repeatability of the measurement process at the bin 3 and lower standards under the Tier 2 regulations, and the ULEV and SULEV standards of the LEV II requirements. Exhaust simulators and zero blank emission test runs should demonstrate these attributes. Since one of the key variables in the volume measurement for BMD and CVS is temperature accuracy and measurement, it is recommended that the flow stream be verified in both unheated and heated modes at low, mid, and high flow rates. Response rates and transport delay times for the proportional sample should also be verified using a simulated step change in gas concentration and flow. These same quality tests can and should be applied to the enhanced CVS sampling system, although response and transport delay are less critical.

EPA is not requiring or recommending any specific design for either the CVS or BMD, but it is recommended that each measurement system be characterized for its accuracy and repeatability under Tier 2 and LEV II requirements. Commercial vendors of these systems need to implement tests to provide data for the potential customer. Special tests have been developed to enable the quantification of the lower detectable limit and associated confidence interval for an emission level.

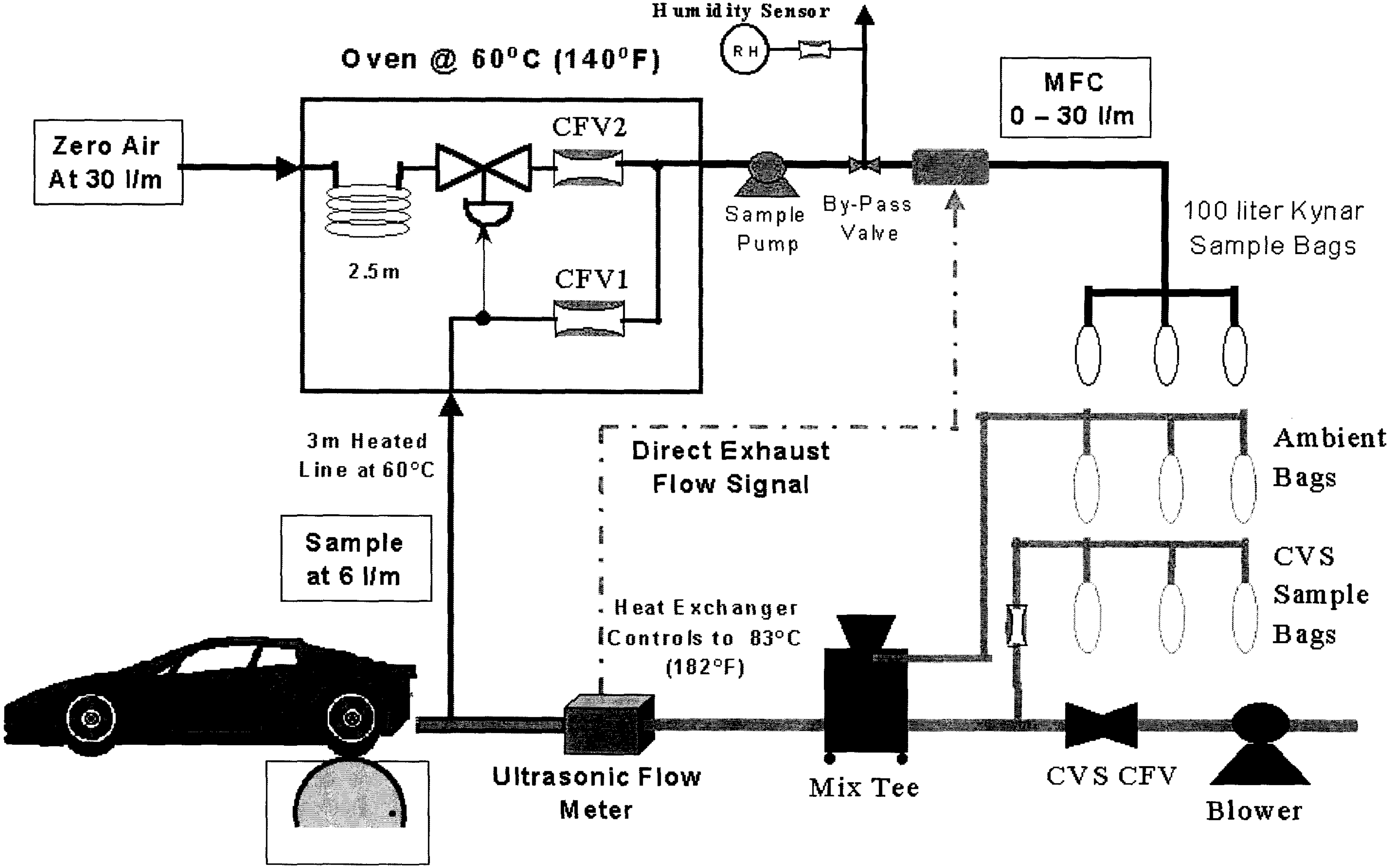
Manufacturers applying for certification based on data submitted from their laboratories need to know and be able to provide the capabilities of their systems, whether the CVS or BMD method is used. Even within a particular sampling system methodology, labs may use variations on the basic scheme, such as the use of MFCs versus CFVs for the BMD dilution control. Both systems provide the functional capabilities for measuring vehicle mass emissions, but only through characterization and quality monitoring tests can system performance be determined. EPA is working with the industry to develop a set of recommended practices and quality control techniques to standardize this process. A review of the technical data provided on the mentioned website as part of the USCAR BMD application will provide the insight to the tests and data that need to be collected. Other laboratories applying to utilize a BMD or enhanced CVS system may be required to submit the data and test results they collected to assure EPA of measurement comparability, capability, and integrity.

The table below presents an overview comparison of the CVS and BMD sampling systems.

Functional Characteristics of CVS vs BMD Systems

CVS	BMD
Variable dilution rate of total exhaust diluted with large flow of ambient air	Constant dilution rate of partial exhaust diluted with small flow of heated dry zero grade air
Real-time continuously proportional sample using small symmetrical CFV near main CFV	Time delayed continuously proportional sample using MFC controlled by exhaust flow signal
Integration of total dilute mixture volume	Integration of total raw exhaust volume
Analysis of sample and ambient bags	Analysis of sample bag only
Calculation of DFc based on CO2 theory	Measurement of DFm based on flow calibrations
Measurement and subtraction of two very small concentrations	Measurement of one very small concentration
Mass = MixVol(Samp - (1-1/DFc) Amb)Dens OR if mixture and dilution volumes are measured and sampled proportionally: Mass = (MixVol*Samp - DilVol*Amb)Dens	Mass = ExhVol*Samp*DFm*Dens

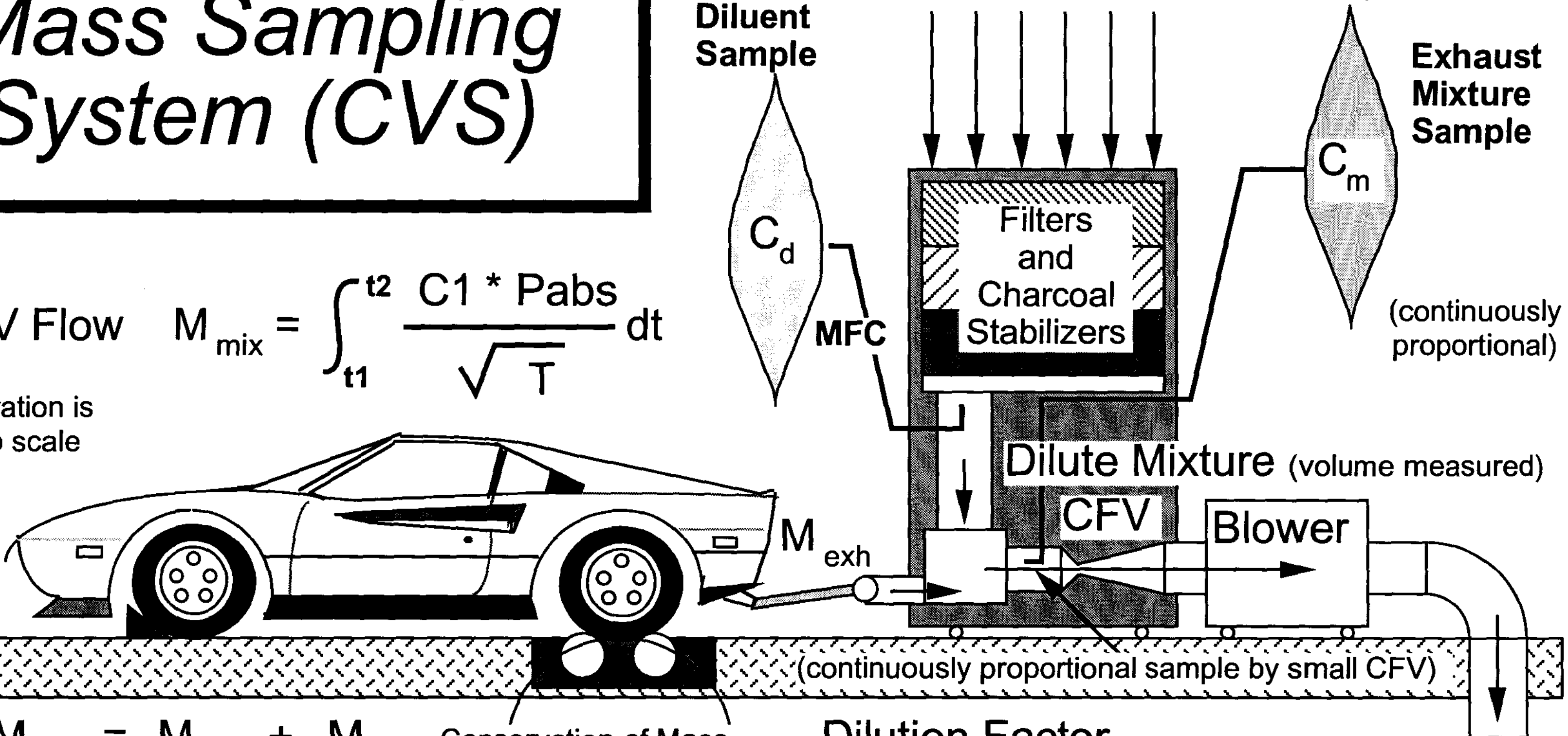
Schematic of Improved Bag Mini-Diluter



Proportional Mass Sampling System (CVS)

CFV Flow $$M_{mix} = \int_{t1}^{t2} \frac{C1 * Pabs}{\sqrt{T}} dt$$

Illustration is not to scale



$$M_{mix} = M_{exh} + M_{dil}$$

$$C_e M_{exh} = M_{mix} C_m - M_{dil} C_d$$ For a specific gas component

$$C_e M_{exh} = M_{mix} C_m - C_d [M_{mix} - M_{exh}]$$

$$C_e M_{exh} = M_{mix} [C_m - C_d (1 - 1/DF)]$$

Exhaust emissions are defined in CFR 86.082-2(b) as only what comes out, not (out-in). Therefore, mass emissions can not be less than ZERO. Typical errors in calc'd DF cause an oversubtraction of the CVS ambient contribution.

Dilution Factor

Definition of actual measured DF = (1 + Dil Ratio)

$$DF = M_{mix} / M_{exh}$$

Based on stoichiometric burn of $CH_{1.85}$ fuel, the estimated

DF = 13.4% / (%CO2 +(THC + CO).0001)

About 99.9% of the denominator carbon is in the CO2.
The more chemically and technically correct DF formula is
DF = 13.4698 % / (%Mix CO2 - (1-1/DF)*%Amb CO2) + ...)

$$M_{exh} = M_{mix} [1/DF]$$ Amb CO2 is about .04% Intake CO2 passes thru

Lean burn and fuel shutoff also cause calculated DF to be higher, but (1-1/DF) changes 1% for a 10% error in DF @ DF = 10